

The use of more efficient vehicles and alternative fuels will go a long way toward easing U.S. dependence on petroleum...

*National Energy Strategy
February 1992*

- Electric cars and vans that travel 400 km (250 mi) on a single charge
- Gas turbine engines that are energy-efficient and low-maintenance
- Nonpolluting fuels that are made from domestic renewable resources
- Quiet, sleek, energy-efficient trains that travel at speeds in excess of 280 km/h (175 mph).

These are just some of the technological advances that are being pursued by the U.S. Department of Energy (DOE) through its Office of Transportation Technologies (OTT)—critical technological advances that can give us a new, improved national transportation system. These technologies can help us to reduce the nation's dependence on foreign oil, increase employment, decrease pollution, and help balance the trade deficit.

OTT supports the development of critical transportation technologies that are often too risky for private industry to develop on their own. OTT works with industry researchers through our national laboratories, often in 50-50 funding partnerships, to speed up the transfer of technological advances in electric vehicles, alternative fuels and fuel additives, and energy-efficient gasoline and diesel engines.

Technology transfer is accomplished through OTT's three major divisions. These divisions are striving to create an interconnected network of new transportation options for the nation's future.

OTT's **Office of Propulsion Systems** supports research for the development of several new types of engines, gas turbines, advanced diesels, and electric and hybrid systems. The gas turbine and

diesel research is closely connected to research conducted through the other units of OTT. For example, some of the engines being developed by OTT propulsion systems researchers will have alternative fuels capabilities and incorporate many ceramic and high-temperature components.

The use of gas turbines to power vehicles could result in a 30% increase in fuel economy over today's internal combustion engines (ICEs). This is possible because, unlike ICEs, which require many moving parts, the gas turbine's power results from the turning of a single rotor. Add the high-temperature tolerance of ceramics and ceramic alloy components to the gas turbine designs and even more complete fuel combustion occurs, further decreasing emissions because of cleaner fuel burn.

Researchers at Oak Ridge National Laboratory (ORNL), Allison Gas Turbine Division of General Motors, and Garrett Auxiliary Power Division of the Allied-Signal Aerospace Corporation are among the key players in OTT's drive to develop these engines.

Ceramics and high-temperature combustion systems also play a major role in OTT-supported diesel engine research. Working with companies such as Detroit Diesel Corporation and Cummins



In addition to supporting advanced automotive research, DOE's Office of Transportation Technologies helps fund educational activities such as this Natural Gas Vehicle Challenge.

Office of Transportation Technologies

Engine Company, OTT is helping the diesel industry to develop concepts and demonstrate engine systems that are more energy efficient and will comply with increasingly stringent federal and state emissions regulations.

Electric vehicles (EVs), another OTT research option, produce no emissions during driving operations. OTT's support of EV research focuses on battery development. Conventional lead-acid batteries, though recently improved, still cannot deliver the range and power necessary for widespread consumer acceptance of EVs at a range of at least 400 km (250 mi) and speeds of 105 km/h (65 mph). OTT researchers at Sandia National Laboratories and Argonne National Laboratory (ANL) continue to work with several industry partners to develop new battery systems that can be installed in EVs, specifically in the integrated system designs developed in cooperation with Ford Motor Company.

OTT is striving to have all of these new technologies available within the next ten years, but what comes after that? Fuel cells. Fuel cells are systems that use liquid fuels to generate electricity on board the vehicle. They don't require recharging, are greater than 50% fuel-efficient, and emit minimal-to-zero pollutants. OTT's fuel cell research is providing for a long-term transportation option.

OTT's **Office of Transportation Materials** focuses on four programmatic areas: ceramics, metals and metal alloys, tribology, and operation and maintenance of the High Temperature Materials Laboratory in Oak Ridge, Tennessee. These programs support the propulsion systems and alternative fuels research conducted through the other OTT offices. Scientists at ANL and ORNL are developing

new materials and lubricants, analyzing materials' structural and operational characteristics, and gauging alternative-fuel compatibilities.

OTT's **Office of Alternative Fuels** supports research to provide a foundation for a domestic renewable fuels industry. OTT's research will help to usher in fuels such as ethanol and methanol, and integrate fuels such as natural gas and propane into the transportation energy mix.

Researchers at the National Renewable Energy Laboratory are working with renewable biomass feedstocks—trees, grasses, and agricultural and industrial residues—to develop low-cost conversion processes for producing ethanol, methanol, and additives for reformulated gasoline. Other scientists and engineers across the country are investigating the use of ethanol, methanol, natural gas, and propane in vehicle demonstration fleets. All aspects of vehicle performance, maintenance, and cost are being scrutinized so that the most practical and economic combinations of alternative vehicles and fuels can be brought to commercialization.

OTT's support of such transportation alternatives is simply a matter of good economics. The application of these new, critical technologies can mean new jobs and businesses, more exports, fewer imports, and a cleaner environment, all of which add up to billions of dollars in gross national product, millions saved in unemployment, and a healthier, cleaner nation.

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Student Vehicle Competitions— government and industry sponsoring tomorrow's engineers

For America's alternative-fuel vehicle (AFV) efforts to be successful, and help our nation reduce its oil dependence and clean up its air, one necessity is a continuing pool of talented, innovative engineers. A slate of events sponsored by the U.S. Department of Energy (DOE) is helping to identify and encourage young engineering talent, give students early hands-on experience, promote AFVs and even advance the state-of-the-art.

A wide range of AFV student events

Since 1988, over eight thousand high school and college students, ranging in age from 14 to the early 20s and representing more than 150 institutions, have participated in DOE-sponsored alternative-fuel vehicle competitions. The annual events include opportunities to build vehicles running on cleaner, domestically-produced fuels such as methanol, ethanol, natural gas and electricity. One of the largest events is the Hybrid Electric Vehicle (HEV) Challenge, which calls upon university teams to develop both conversion and ground-up

HEVs, and match their vehicles against those of other schools. HEVs, considered to be one of the most practical alternative-fuel vehicles in the short term, combine internal combustion engines with electric power, providing a desirable combination of performance, range, and low emissions.

The events are structured in a number of different ways. A recent American Tour de Sol, for example, was open to every group with an electric vehicle (EV). This competition was a road rally from New York City to Philadelphia, with prizes going to the vehicles demonstrating the greatest range. A recent Arizona Public Service Electric 500 allowed high school teams the opportunity to compete their EVs for evaluation in events including acceleration, range, efficiency, design and oral presentation. The HEV Challenge is open to university teams by proposal only, and chosen entrants vie for honors in practical areas including range, emissions, acceleration and efficiency. In addition, special awards are given for the best use of materials, most manufacturable design, safest design and

many other achievements. There has even been a "paper designs only" event, allowing an even wider range of entrants to present their ideas.



The Michigan State University team members and the Spartan Charge, their award-winning entry in the 1993 National Hybrid Electric Vehicle Competition

Student Vehicle Competitions

Getting students excited about engineering—and giving them the practical experience to succeed

Interviews with participating students draw comments such as "I felt like a real engineer," "It's more than a text book can ever offer" and "It's the best learning experience I've ever had." For many students, the events may represent their first or most substantial experience with a "real world" project. They're building or converting an alternative-fuel vehicle with their own hands, with all the thrills and challenges that that entails. On the technical end, they learn to apply engineering theory to an actual working vehicle. Many get the opportunity to prepare a paper or make an oral presentation on their design to professional engineers, and see their names in the growing technical literature. They meet and work with industry professionals, perhaps laying the groundwork for a future career. In addition, students develop the vital real world skills of dealing with vendors, raising and managing funds, and perhaps most importantly, working together with diverse people as part of an effective team that designs, constructs, and tests a vehicle.

Tomorrow's engineers can be today's innovators

As one sponsor put it, "put several hundred new engineers with fresh eyes to work on a task, and you never know what they'll come up with." A few teams have in fact forwarded the state-of-the-art through their student competition efforts. Teams from Old Dominion University and Northwestern University, for example, created new advancements in the area of natural gas vehicles. The latter developed a natural gas fuel sensor that allows the engine to adapt to varying natural gas compositions, a problem that has long been a challenge to experts. Both schools are currently working with corporate partners to refine their designs.

In addition, many participating schools have received governmental and corporate research grants based on the performance of their designs at student competitions. These "research spillovers" amount to more than \$1 million in research on the part of the schools.

Strong support from government and industry large and small

DOE provides funding, prize money, and, through its team at the Argonne National Laboratory, substantial personnel time in organizing and coordinating student competitions. In the private sector, the Big Three automakers are also substantial supporters. Ford, General Motors and Chrysler have all given students standard production vehicles to convert, and their people have provided outstanding guidance to the young engineers.

Electric utilities, such as Arizona Public Service, Detroit Edison, and Virginia Power, have been active and generous sponsors, as have auto industry suppliers and trade associations such as the Society of Automotive Engineers (SAE). Invaluable assistance has also been provided by hundreds of local businesses which provide their high school and college teams with everything from equipment to team T-shirts to much-needed travel funds.

Helping to spread the word about alternative-fuel vehicles

Building a vehicle, especially for high schools, often becomes a big community event. The entire school becomes involved in technical aspects, in promotions or in raising funds, and the word is spread to parents, friends and local businesses. Local media report on the efforts, and national and international media often cover the events. This adds up to hundreds of thousands of people learning about characteristics and benefits of alternative-fuel vehicles. These student competitions will help pave the way for AFV acceptance as engineers like these talented students help make them technically and economically viable for everyday use.

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High Temperature Materials Laboratory— providing researchers with the equipment and support they need to forward transportation materials technology

Advanced high-temperature materials such as ceramics and intermetallic alloys can play an important role in improving the efficiency of transportation engines, and help America meet its economic, environmental and energy security goals. For example, ceramic parts are better than metal parts at withstanding heat and aggressive environments found in the most sophisticated, high efficiency engine designs. However, a number of issues, including material brittleness, proper lubrication (tribology) and practical manufacturing and processing procedures need to be addressed before

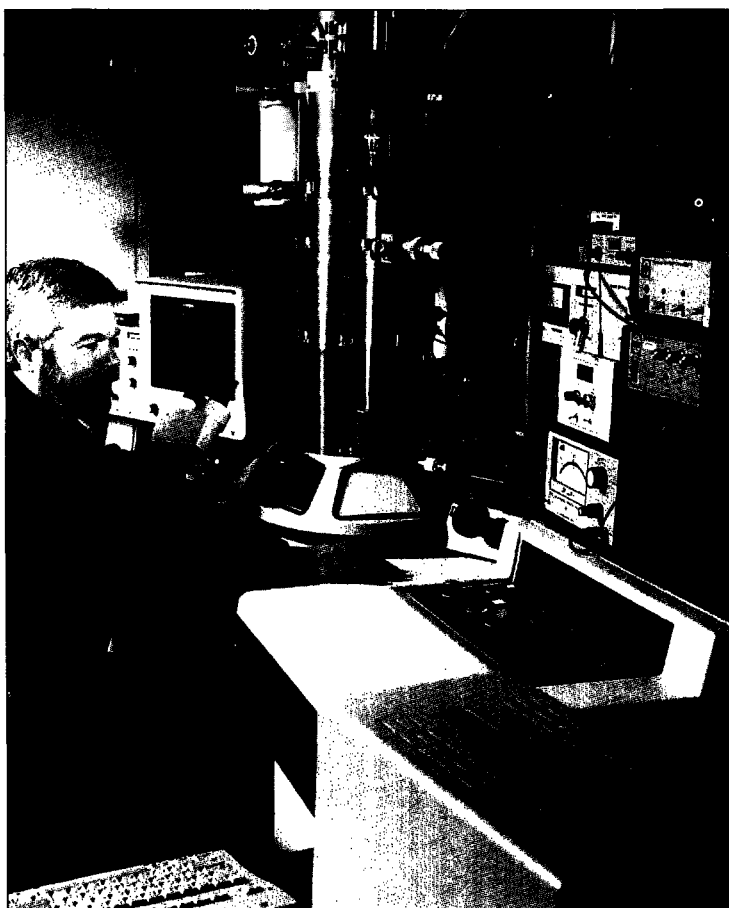
the benefits of high-temperature materials can be brought to mass market transportation applications.

Teams of scientists and engineers in many countries are actively working to develop solutions to these and other technical barriers. However, because many of these areas of research are so new and so specialized, few individual companies and institutions can afford to invest in the extensive array of sophisticated instrumentation needed to test and evaluate high-temperature materials, lubricants and related data and models. As a result, many of America's most innovative materials

researchers would be unable to prove out their ideas and advance the materials technologies that could lead to significant economic, environmental and energy security benefits for the United States.

HTML provides centralized access to state-of-the-art equipment and expertise

This was one of the drivers leading to the creation of the High Temperature Materials Laboratory (HTML) on the grounds of the Oak Ridge National Laboratory in Tennessee. HTML's seven state-of-the-art User Centers provide researchers from industry, government and academia with hands-on access to the equipment they need to characterize the microstructure and microchemistry of ceramics and intermetallic alloys, and investigate the materials' physical and mechanical properties.



Dr. Larry Allard operates the Hitachi Field Emission Gun Analytical Electron Microscope in the Materials Analysis User Center of the High Temperature Materials Laboratory.

High Temperature Materials Laboratory

Research instruments and facilities at each of the User Centers include, but are not limited to:

- *Materials Analysis User Center:* Scanning Auger Microprobe, Scanning Electron Microscope, Analytical Electron Microscope, complete specimen preparation facilities and Macintosh-based computer network for imaging and data needs.
- *X-Ray Diffraction User Center:* High Temperature X-Ray Powder Diffractometer with Furnace.
- *Residual Stress User Center:* Polycrystalline Texture Stress Goniometer, Neutron Diffraction Macro Residual Stress Mapping Facility, Micro Residual Stress Neutron Powder Diffraction Facility.
- *Physical Properties User Center:* Dual Push-Rod Dilatometer, Differential Scanning Calorimeter, Simultaneous Thermal Analyzer, High Temperature-High Mass Thermogravimetric Analyzer.
- *Mechanical Properties User Center:* High Temperature Tensile Test Facilities for Ceramic Monofilament Fibers, High Temperature Tensile Test Facilities for Flat and Cylindrical Monolithic Ceramic and Ceramic Composite Specimens, Ceramic Flexure Test Facilities, Electromechanical Test Facilities.
- *Ceramic Machining User Center:* Multiaxis Cylindrical Grinder, Instrumental Surface Grinder, Laser Surface Profilometer, Formtester, Ultrasonic Modulus System.
- *Ceramic Manufacturability Center:* Coordinate Measuring Machine, Surface Grinder, Centerless Grinder, Milling Machine, Computer System with Three Dimensional Modeling Capability.

In addition to providing this wide range of equipment, HTML's User Centers are also designed to be user friendly. For example, technical experts are available at all times to provide on-site assistance to their private sector colleagues, train them

on the use of various instruments and, where needed, even help to analyze and interpret results.

Convenient office space and other amenities are available for visiting researchers performing longer-term investigations. And, there is no charge for use of the equipment for those performing open research. Those performing proprietary research gain access on a cost-recovery basis.

Since 1987, researchers from more than 35 American companies and 50 universities have utilized HTML facilities, as have dozens of researchers from federal laboratories.

Fellowship program encourages materials research

In order for the U.S. to maintain global competitiveness in materials sciences, talented scientists and engineers need to be encouraged to enter materials research arenas. Towards this end, the U.S. Department of Energy (DOE) sponsors a series of fellowships for researchers at several levels, including graduate students, postdoctoral researchers, faculty members and industrial researchers. The fellowships offer training and the opportunity to further education and experience on state-of-the-art equipment, as well as providing access to expert technical staff. The fellowship appointment terms range from one month to four years. To be considered, candidates must meet criteria including involvement in areas that tie in with DOE transportation materials program areas, such as study of ceramic properties at high temperatures, ceramics processing and tribology.

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Light-Duty Vehicle Emissions Testing Program— generating AFV emissions data to aid potential operators

Replacing a quantity of vehicles running on gasoline with alternative-fuel vehicles (AFVs) can help the United States clean up its air, reduce its dependency on foreign petroleum products and create domestic jobs in new industries. Indeed, the use of AFVs is being federally mandated for several types of light-duty vehicle fleets. This means that thousands of fleet operators will soon need to make a strategic choice from among several types of vehicles, weighing such factors as overall cost, reliability and emissions performance.

Ironically, the AFV information that is probably the most important is also the most challenging to collect—that is the relative emissions of such regulated pollutants as hydrocarbons, carbon

monoxide and oxides of nitrogen. This information is needed by private and public sector fleet operators alike in order to make the most effective choices for their own fleets and ensure that they're able to meet all emissions requirements.

Test equipment, however, is very specialized, and must be operated by trained technicians experienced in specific federal test procedures in order to get meaningful measurements. As a result, qualified test sites are few and far between, and the test itself can be cost-prohibitive for the typical fleet owner.

M85 flexible-fuel Taurus undergoing emissions testing at environmental research and development



Light-Duty Vehicle Emissions Testing Program

DOE program gives decisionmakers the information they need

The Light-Duty Vehicle Emissions Testing Program is designed to determine the extent of differences in emissions between alternative-fuel light-duty vehicles and their gasoline counterparts. Vehicles being studied include those running on different concentrations of ethanol and methanol, as well as compressed natural gas. Vehicles operating on reformulated gasoline are also being tested for comparison.

There are several hundred vehicles in the Program, including cars, vans and pickups, the most common types used in light-duty fleets. They are tested at regular intervals utilizing the mandated federal test procedure, which simulates vehicle operation in a controlled environment by use of a chassis dynamometer.

The vehicles involved are part of the Federal Fleet Program, a U.S. Department of Energy (DOE) effort geared toward getting more AFVs out on American roads. Several fleet locations were chosen to participate, based on such factors as fleet size and types of vehicles. Relative altitude was also a factor, as altitude of operation can significantly impact emissions. Both high (Denver) and low

(Washington, DC) altitude sites are represented in the test data.

In addition to emissions data, the Program also collects other AFV information that may be valuable to fleet operators. This includes maintenance records, fuel economy data, reliability, driver perceptions and more.

Information accessible through AFDC

All this data and more is sent to the Alternative Fuels Data Center (AFDC), DOE's "central clearing-house" for AFV information. Here it can be accessed by modem, giving fleet operators the facts they need to make the best decision for their organizations. Information can also be acquired through the National Alternative Fuels Hotline at 1-800-423-1DOE.

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Hybrid Electric Vehicle Program— building a low emissions vehicle for widespread use in the short term

Electric vehicles produce no emissions but, with current technologies, provide limited range and performance. Internal combustion vehicles, such as today's automobiles, provide satisfactory range and performance, but produce significant emissions.

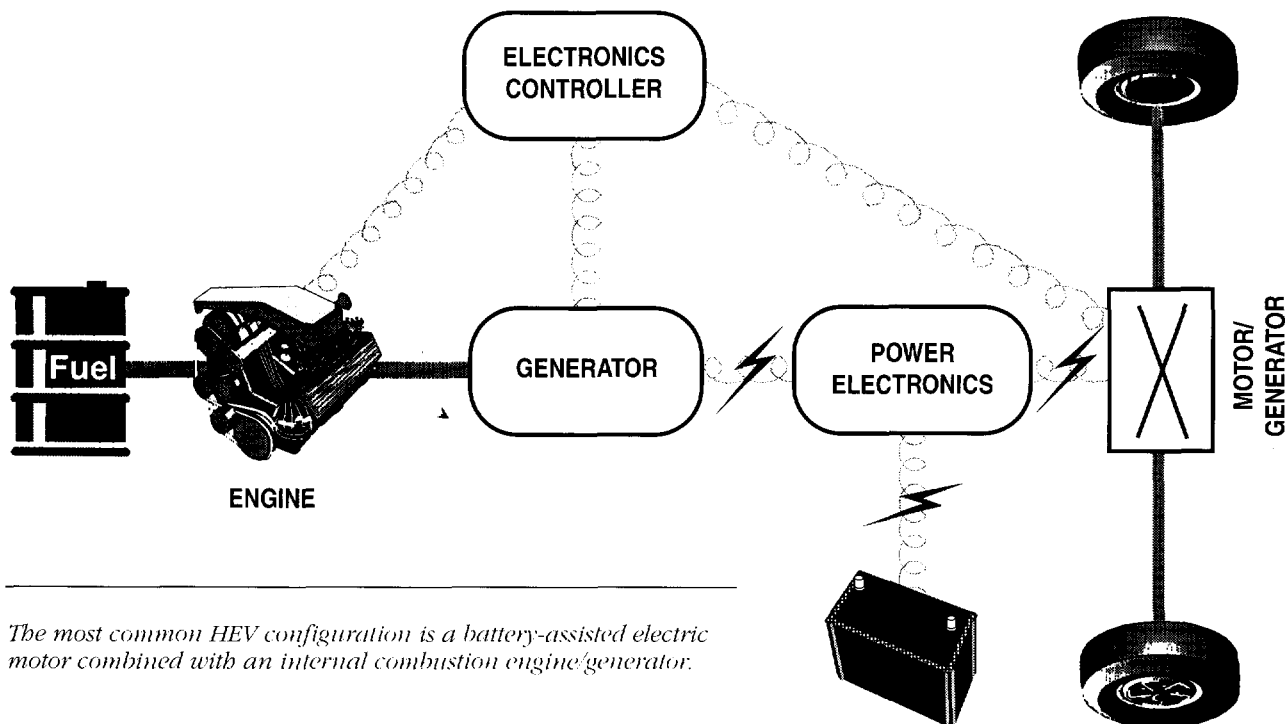
In one of the newest programs sponsored by the U.S. Department of Energy (DOE), competitive industry teams are working to produce a vehicle that combines the best features of both technologies—and make it available for the mass market perhaps as early as the next decade. The success of the Hybrid Electric Vehicle Program would help improve the environmental performance of the automobile, reduce American dependence on foreign oil, and help reshape the international auto industry.

Hybrids—the best of both worlds

As their name suggests, hybrid electric vehicles

(HEVs) use more than one method to convert stored energy to propulsion energy. The most common configuration is a battery-assisted electric motor combined with an internal combustion engine/generator operating on traditional gasoline or alternative fuel such as ethanol.

At face value, HEVs produce fewer emissions than conventional vehicles because they burn less fuel to go the same distance. However, a combination of the two systems offer engineers additional opportunities to build-in energy-saving innovations. For example, HEVs can store excess electrical energy during coasting, idling and other periods of low power demand, which can then be drawn upon during periods of high power demand. HEVs also recover the energy that would normally be lost when braking a conventional vehicle and store it for later use. For these reasons, an HEV internal combustion engine can be smaller than the engine



The most common HEV configuration is a battery-assisted electric motor combined with an internal combustion engine/generator.

Hybrid Electric Vehicle Program

in a comparable conventional vehicle, improving fuel efficiency and environmental performance when in the non-electric mode. When the internal combustion engine is operated using non-petroleum fuel, emissions are reduced even further.

Acceptable to consumers

The basic technologies that make HEVs possible already exist, many of them developed in DOE laboratories over the past 20 years. In addition, it is understood that HEVs have an inherent "head start" over other forms of alternative transportation because they can offer the range and performance consumers are accustomed to, are similar in appearance to conventional automobiles, make use of existing infrastructure (gas stations), are easy to re-fuel, and provide competitive life-cycle costs. For these reasons, there are fewer practical barriers that could hinder short-term production and market acceptance of HEVs.

DOE-sponsored teams building a prototype for mass-production models

DOE announced a request for proposals in late 1992, inviting industry teams to submit a plan for developing an HEV prototype that would meet several goals. Among them, that the prototype would be at least twice as fuel efficient as current production models, that it would meet the Environmental Protection Agency's Federal Tier II emissions standards (equivalent to California Ultra-Low Emissions

requirements), and that overall costs, safety standards and range and performance levels would be competitive with current vehicles.

Out of seven proposals submitted, two were chosen—those of teams led by General Motors Inc. and Ford Motor Company. The General Motors agreement, with government/industry cost-shared funding of \$138 million, includes 11 team members. The Ford contract, cost-shared at \$122 million, includes 17 subcontractors.

Towards the end of a five-year development and testing period, each team will present a state-of-the-art prototype hybrid electric vehicle. It is hoped that these designs will achieve the levels of cost-effectiveness and consumer acceptance that would lead directly to production vehicles by the 2001 model year. Federal orders for the vehicles could begin as early as the 1998 fiscal year, helping to get the vehicles on the road and familiar to American consumers. The possibility of DOE involvement in longer-term HEV research programs will be determined at a later date.

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The National Alternative Fuels Hotline— Experts standing ready to answer questions on all aspects of alternative fuels and vehicles

The Alternative Motor Fuels Act (AMFA) of 1988, pointing to the potential for lower vehicle emissions and reduced dependence on imported oil, calls for, among other things, encouraging Americans to investigate and utilize cleaner, domestically-abundant alternative fuels such as natural gas, propane, methanol and ethanol. As a result of AMFA, DOE established many R&D programs geared toward improving the technologies that would make alternative-fuel vehicles practical for American business and, ultimately, consumers. With the passage of the Energy Policy Act of 1992, programs to promote alternative fuels were given even greater emphasis, and it became apparent that there needed to be an "information dissemination" component to the effort—there needed to be a mechanism by which the latest, unbiased alternative fuel information could be passed on to all interested Americans in a timely and convenient manner.

Call 1-800-423-1DOE for alternative fuel answers

This was the genesis of the National Alternative Fuels Hotline, established by DOE's Office of Transportation Technologies in 1992. The Hotline—available toll-free weekdays from 10 am to 6 pm eastern time—provides objective answers to questions relating to many areas of alternative fuels and vehicles.

The Hotline averages up to 100 calls per day, fielding questions for a very wide and diverse caller constituency. These include fleet operators, financial analysts, fuel providers, auto manufacturers, university professors and teachers, students of all ages, state and federal agencies, inventors and jour-



nalists, as well as people who are just generally interested.

Questions asked are as diverse as the callers who ask them, from the simple need of an elementary

school student wanting to know "what is an alternative fuel" to the highly technical need of a fleet operator looking to gain better understanding of the impact of federal regulations on company operations. Through thousands of calls, Hotline information specialists have fielded an ever-growing diversity of questions touching upon general, technical, regulatory, administrative and many other areas of the alternative fuel and vehicle universe.

As the word "gets out" on the availability of the Hotline, call volume has been increasing steadily. Calling "spikes" often correspond with mentions in prominent publications, or when there is alternative fuel-related news in the headlines.

Staffed by experts backed by extensive informational resources

With calls increasing in diversity and volume, Hotline information specialists must have extensive knowledge, versatile skills and access to many resources.

The National Alternative Fuels Hotline



As a start, Hotline information specialists have strong backgrounds in alternative fuels. Many come from assignments as editors or journalists covering alternative fuel issues; others were formerly involved with Department of Energy R&D programs at DOE offices or laboratories.

In addition, information specialists are constantly updating their knowledge through literature monitoring and professional research, as well as through contact with experts in many alternative fuel-related industries. Perhaps most importantly, they receive frequent updates from DOE programs which are "pushing the envelope" of alternative fuel and vehicle knowledge, including the Federal Fleet Program, Alternative Fuel Truck Application Program and the Emissions Testing Programs.

Interestingly, callers themselves are often a source of new insights. By sharing call details, information specialists can help determine those issues of major public interest, and ensure that the needed resources are close at hand. Information specialists are linked to each other through a computer local area network (LAN), so they can share new information with each other, avoiding duplication of effort and keeping everyone on the cutting edge.

Diverse skills help provide excellent service

Gaining and sharing knowledge, however, is only one facet of the information specialists' job. Other requirements include expert interviewing skills to

be able to "draw out" questions from a caller base of widely varying ages, backgrounds and educational levels. Specialists must have excellent researching skills, able to quickly tap into many resources—verbal, written and electronic—to get answers to caller questions or know where to refer them. And, of course, they must have a pleasant phone manner. To help fine tune these skills, they are trained by "listening in" to other specialists' calls before getting on the phones themselves.

Expertise utilized in several ways

The Hotline information specialists represent a valuable central source of up-to-the-minute alternative fuel and vehicle information, and DOE has been working to make maximum use of this valuable resource. To help others benefit, knowledge is disseminated through a number of other avenues, including brochures, pamphlets, press releases and newsletters. In the latter, current "hot questions" are reprinted for a wider audience.

The Hotline is also tied in with the Alternative Fuels Data Center (AFDC), an online resource with a continuously-updated data base. AFDC is fed by operators of in-service alternative-fueled vehicles, who provide data such as emissions test results, fuel analysis reports and maintenance records. Hotline personnel can help qualified users download this information.

The National Alternative Fuels Hotline has met with such positive response that it is being used as a model for other public service efforts. For example, a new Hotline fielding questions regarding the DOE's Clean Cities program has been established along similar lines.

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Biofuels Systems Program's Feedstock Development R&D— Developing new, cost-effective alternative fuel crops

Ethanol, whether by itself or blended into gasoline, offers a number of benefits as a motor fuel. It is potentially cleaner than petroleum-based fuels, offering the possibility of reducing carbon dioxide and other emissions. It is a high octane liquid fuel that can be produced domestically. And, as a biofuel made primarily from plants, it is renewable, whereas the world's oil supplies are finite.

However, the widespread use of ethanol is limited by a number of factors which serve to make it more expensive than gasoline on a gallon-equivalency basis. One such factor is the cost of feedstocks, which currently account for about one third of the price of the fuel. Corn and wheat are the main crops used in ethanol production today. Although plentiful, these crops have high value as food and animal feed, so their ability to serve as feedstock for fuel applications are limited.

Cultivating nontraditional feedstocks

The Biofuels Systems Program's feedstock development R&D is aimed at developing low-cost, high-yield crops that can be used primarily for energy applications. Biofuel and electric power producers are already considering these crops for displacing coal and reducing oil imports.

The focus of DOE's research is on fast-growing grasses and trees. Cooperating universities and U.S. Department of Agriculture research facilities have screened more than 120 different species in multi-year experiments. While many species show promise as energy crops for the near future, switchgrass and several varieties of hybrid poplar trees were identified as the most promising crops. R&D efforts revolve around lowering production costs and increasing yields. Efforts so far have succeeded in reducing costs to \$3.25 per million Btus, and in increasing yields from two to six tons per acre. The



Researchers are working to genetically improve poplars by combining traditional breeding methods with advanced molecular biology techniques.

goal of the R&D effort is to produce an average biomass yield of 10 tons per acre at a cost of \$2.00 per million Btus.

Providing benefits to farmers

The opportunity to grow these new energy crops on their acreage could have significant benefits for America's farming sector. Trees and grasses can provide farmers with a more diverse range of land-use and cropping alternatives, as well as help reduce land erosion and retain organic matter. Because trees and grass crops are perennial rather than annual, soil disturbance is minimized, nutrients are recycled internally and wildlife value is

Biofuels Systems Program's Feedstock Development R&D



A farmer harvests a field of switchgrass, which is an excellent energy crop for biofuels production. A hearty perennial, this thick-stemmed grass can grow higher than 6 feet tall and its roots extend more than 2.5 feet into the ground, which enables it to survive in depleted soils. It is harvested like regular hay.

improved. To reduce inputs of fertilizers and pesticides, energy crops are being selected for efficient nutrient use and resistance to pests and diseases.

Partnerships with private and public sector organizations

The more than a dozen individual feedstock development efforts underway include work being done with private sector organizations such as major corporations, academic institutions, wildlife societies, as well as joint efforts with the U.S. Department of Agriculture. Environmental and economic analyses are underway at DOE's Oak Ridge National Laboratory, which also provides field management for the effort.

One standout project is an effort with paper producer Boise Cascade established under a Cooperative Research and Development Agreement (CRADA), a new way of working that streamlines the process of private and public sector partnering.

The effort involves gaining insight into the biochemical basis for drought tolerance in hybrid poplars. This could lead to the development of a draught tolerant hybrid poplar, which would save substantial irrigation costs and lower the costs of production of both paper and biofuels—a win for both partners.

Healthier air—and a healthier economy

A major American biofuels industry could bolster the domestic farm economy, potentially lowering the need for government subsidies. It could also create jobs not just in the agricultural arena, but in sectors including engineering, financing, vehicle manufacturing and fuel conversion. In addition, a successful biofuels industry would significantly decrease American dependence on imported foreign oil, bolstering our energy security and balance of trade.

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Biofuels Systems Program's Conversion Technologies R&D— Developing new, cost-effective methods for converting biomass to liquid fuels

Ethanol and methanol fuels offer a number of benefits. Standing alone or blended-in, they are potentially cleaner than pure gasoline. In addition, they are domestically produced and renewable. Unfortunately, alcohols are generally less cost-effective to produce than gasoline, a major impediment to their widespread acceptance.

In the United States today, most ethanol is made from edible grains such as corn, and most methanol is produced from natural gas. Since both feedstocks have great value in other areas—corn as food and feed and natural gas in countless processes—it is believed that one way to ensure the volumes of alcohol needed to displace a significant amount of imported oil—and do so at a competitive price—is to develop other, dedicated sources of feedstock. Both ethanol and methanol can be produced from plant biomass, and research is underway to develop low cost biomass feedstocks.

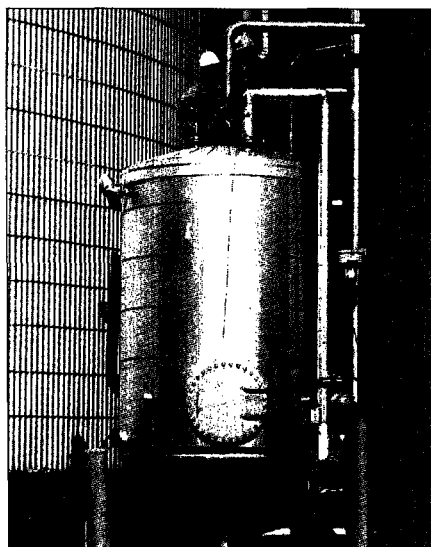
However, feedstocks are only part of the solution—the other key to success is developing new technologies to convert both traditional and nontraditional crops to alcohol fuels in a manner more cost-effective than possible today.

This is the focus of the Biofuels Systems Program's Conversion Technologies R&D, underway at the National Renewable Energy Laboratory (NREL). With the assistance of a number of private sector researchers and partners, research is being conducted in both ethanol and methanol conversion areas.

New technologies produce more cost-effective ethanol

The ethanol side of the effort is looking at a number of different processes to cost-effectively convert biomass to alcohol fuel.

One of the first such projects is working to make more effective use of corn—the most widely used feedstock in the short term. Although, as noted, corn will cost-effectively meet only part of the future demand for ethanol, there is an opportunity to increase the plant's ethanol yield. Current commercial technology only allows the conversion of the starch component of the kernel. An effort is underway to utilize the cellulosic fiber of the kernel as well, which could improve yields by some 23%. The effort is being conducted in partnership with New Energy Corporation, and was recently recog-



A process developed as part of a cooperative research and development agreement (CRADA) between NREL and New Energy Company of Indiana, Inc. (New Energy) is expected to increase ethanol yields from corn by up to 13%. This innovative process, which R&D magazine selected as one of the 100 most technologically significant achievements of 1993, enables producers to separate and ferment sugars from the stillage (protein, fibrous material, fats, and some starch) that normally remains after corn has been converted to ethanol using conventional processes. New Energy recently constructed a \$1 million pilot plant, which is being used to test the new conversion technology at the firm's South Bend, Indiana facilities. The potential also exists to use low cost feedstocks like corn cobs and stover as well as other crops like grasses and trees in the new conversion process. Shown here is one of two 8,000-liter fermentation tanks at the New Energy pilot plant.

Biofuels Systems Program's Conversion Technologies R&D



More than 4 billion liters (1 billion gallons) of fuel ethanol are produced annually in the United States—mostly by fermenting the starch found in corn using processes similar to those used to make beer and whiskey. Before corn can be fermented, it must be ground. Current Department of Energy research is developing new conversion technologies that will enable producers to make ethanol from other types of biomass including trees and grasses.

nized as one of the 100 most important technological innovations in an annual study by *R&D* magazine. The New Energy partnership is operating under a Cooperative Research and Development Agreement (CRADA), a streamlining of the process necessary for government and industry to work together.

Many non-grain ethanol feedstocks are cellulosic in nature, and new technologies must be developed to efficiently convert them to ethanol. Studies at NREL and partner sites are investigating a process called simultaneous saccharification and fermentation, which combines two main conversion steps into one, decreasing production time and increasing yields in a drive to lower conversion costs. Work is also being done to develop new enzymes that more economically degrade cellulose to sugar—a key step in the conversion process, and

a number of patents have been filed. Still other efforts focus on improving the pretreatment step of the conversion process.

Another CRADA—this one with Amoco—is also assessing the feasibility of producing ethanol from a number of waste cellulosic materials such as waste paper. This partnership has the potential to not only significantly lower the cost of cleaner-burning domestic ethanol, but also reclaim solid waste and reduce our nation's dependence on landfills.

Making methanol from biomass

The process to convert natural gas to methanol is well-established; however, biomass represents a renewable, potentially cost-effective feedstock supply for methanol production.

Biomass is converted using a thermochemical method called gasification, and a number of efforts are underway to improve the process. For example, in two separate stages of the process, impurities such as tars must be removed, and the proper ratio of component gases must be adjusted. Work is underway to develop a catalyst that can reduce impurities and produce the desired hydrogen-carbon monoxide mix simultaneously.

The result—competitively priced alcohol fuels from biomass

The cost-reduction focus around methanol conversion is to produce the alcohol from biomass at a cost competitive with that produced from natural gas. Ethanol—currently the alcohol more widely used as a motor fuel—needs to go head-to-head with gasoline. Research goals have been established to produce ethanol for 67¢ per gallon and methanol for 50¢ per gallon.

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Biofuels Systems Program's Biodiesel R&D— Replacing petroleum-based diesel fuels with a cleaner, renewable, domestically-produced alternative

Most of our nation's trucks, buses and ships rely on the efficiency, cost-effectiveness and reliability of heavy-duty diesel engines, currently powered primarily by diesel fuels derived from imported petroleum. However, conventional diesel fuel emits particulates into the air, as well as the NO_x , CO_2 and other pollutants emitted by nearly all petroleum-derived fuels. In addition, because of the extent to which our nation's economy is dependent on diesel fuel, long term energy security is of significant concern.

Efficient diesel engines do not necessarily have to use petroleum-derived fuels. Various animal- and vegetable-derived oils have long been used as substitutes, and, in general, long-term biodiesel use necessitates only minor modifications to a diesel

engine system—usually just replacement of hose and fuel line materials in response to the solvent properties of biofuels. Through the years, petroleum-based diesel fuels became the conventional choice—and infrastructure was built around them—primarily because of their relatively low cost.

With recent environmental, economic and energy security concerns, biodiesel—which burns cleaner, can be produced domestically and is renewable and potentially abundant—is again gaining attention as an alternative to petroleum-derived diesel fuels. It can be used in a pure form, or blended with traditional diesel fuel to lower particulate and emissions levels. However, cost is still a major factor, with today's biodiesel priced significantly higher than equivalent petroleum-derived

products, making the fuel impractical for widespread use in a competitive economy.

Working on short term solutions

To assist in the establishment of a viable biodiesel industry, the Biofuels Systems Program is working with private sector groups such as the National Soy Diesel Development Board and the Fats & Protein Research Foundation to develop new processing technologies to help lower the cost and increase the efficiency of biodiesel in the short term. Efforts include R&D around the simulta-



A National Renewable Energy Laboratory researcher holds one of more than 3,000 strains of microalgae that scientists have examined to identify those most suitable for biodiesel production.

Biofuels Systems Program's Biodiesel R&D

neous processing of different oils, as well as cost-effectively converting waste oils—such as those used in restaurants for cooking—to biodiesel. These oils are cheap and readily-available.

It should be noted that, regardless of cost, the demand for biodiesel will be increasing in the short term in several niche markets, primarily because of biodiesel's environmental benefits. One such market is fuel for fleet buses in Federal non-attainment areas, where operators must by law lower the emissions of their vehicles. Other applications include biodiesel use in underground mines, where lower particulate emissions are sought, and applications near watershed areas, where biodiesel's non-toxicity and biodegradability are especially important benefits. The Biofuels Systems Program's short term biodiesel R&D efforts will help ensure the availability of biodiesel for these and other niche markets.

A long term solution to low cost biodiesel

The effort is also looking longer term, with the potential for dramatic breakthroughs in biodiesel production.

The focus is on the production of oil-producing microalgae, grown in large, man-made pools. The lipids produced by the microalgae are very similar to vegetable oils, and can have significant value as fuel.

A team at the National Renewable Energy Laboratory (NREL) is conducting research to produce strains of algae that demonstrate the optimal balance of rapid growth rate and high rates of lipid production. By screening organisms and manipulating growth media, scientists have already increased the lipid content of microalgae from the 5-20% of their natural state to up to 40% in outdoor ponds and up to 60% in the laboratory. It is expected that these levels can be increased even more substantially using genetic engineering tech-

niques. Pioneering research is being done toward this end, as is R&D work geared toward controlling lipid-producing processes, developing economical methods of lipid extraction and optimizing environmental parameters for maximum growth.

The goal of this multi-faceted effort is to produce abundant supplies of biodiesel at a competitive market price by 2010.

Environmental benefits— a win-win with industry

Carbon dioxide is "food" for photosynthetic plants. The amount of CO₂ needed to allow such large volumes of algae to thrive is not available from the atmosphere, but would need to be pumped in from another source. This could be a costly scenario.

Meanwhile, in another sector of the economy, electric utilities are struggling with cost-effective ways to lower their emissions of carbon dioxide, a greenhouse gas that is a byproduct of the power generation process.

DOE and the power generation industry are currently investigating win-win partnership opportunities. With power plants and microalgae ponds located in close proximity, CO₂ flue gas could be fed directly from the stacks to the ponds, providing utilities with a cost-effective solution to their CO₂ emissions clean-up, while significantly reducing the cost of producing biodiesel from microalgae.

This tidy solution can hasten the environmental and economic benefits of biodiesel, benefits which are likely to become much more substantial in the longer term.

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Electric Vehicle Site Operator Program – evaluating technology, building infrastructure and fostering public awareness of clean electric vehicles

Because they are zero-emitting, electric vehicles (EVs) can be a vital part of the effort to improve the quality of urban air. The key is making them practical so they can gain widespread acceptance and use. The Electric Vehicle Site Operator Program is designed to field test preproduction and prototype EVs and related components under realistic operating conditions, and receive and incorporate constructive operator feedback. It is also designed to support the technology base with efforts to build necessary infrastructure and increase public acceptance of new and different vehicle options.



G-Van being used in field testing under Site Operator Program

Tapping into unmatched experience

Collectively, DOE Site Operators and their staffs have driven more than 4 million EV miles, acquiring the largest base of "real world" EV operating experience in the world. Their expertise in identifying and handling problems unique to EVs, including most battery and component failures, is invaluable and does not exist in any other program. Of practical importance is the fact that the Site Operators have gained that EV experience under a wide range of geographic, climatic and urban operating conditions, permitting demonstration of the EV concept to a large segment of the public, countrywide. In addition, many Site Operators are heavily involved in EV R&D and bring a range of technical capabilities to the DOE Program. For example, Arizona Public Service is supporting the development of a zinc/air battery, a bipolar lead/acid battery and advanced electron-

ics; and Kansas State University is involved in developing a parking meter-style station for convenient curbside charging. Many Program participants are recognized as EV technology leaders in specific areas such as testing and evaluation, solar charging stations, technical training and inductive charging, and bring this expertise to bear.

Field testing and evaluating to bolster the EV knowledge base

Testing and evaluating electric and hybrid vehicles, batteries, vehicle systems and components is an integral part of this Program. Currently, the Site Operators are testing more than 22 different types of vehicles in their fleets. Half of the fleets' 120 vehicles are G-Vans; others include the Soleq EVcort, Ford Ecostar, Chrysler TEVans and Solectria sedans. Buses which incorporate state-of-the-art vehicle design, unique components and/or

Electric Vehicle Site Operator Program

new traction batteries (nickel/iron, zinc/air and nickel/cadmium) are being tested or will be tested in the near future.

Building infrastructure

The Program is working to build the infrastructure needed to make EVs a practical reality, and is addressing issues and needs including vehicle support, maintenance, charging stations and training. Some examples of participants' efforts include:

- York College is developing a curriculum for EV technicians.
- Arizona Public Service has supported the formation of an EV sales and service company in the Phoenix area.
- PG&E has been heavily involved in the development and testing of inductive charging technologies, and is also developing a public charging demonstration in cooperation with Bay Area Rapid Transit (BART).
- The University of South Florida in Tampa recently dedicated a solar charging station with facilities for up to 12 vehicles.
- LADWAP recently completed Los Angeles' first public EV charging station, and is planning to install an additional 60 or more over the subsequent 18 months.

Garnering public awareness and interest

Capturing the attention of the public and making them aware of the progress of EV technology through media events, technical displays, publications and other avenues is another important part of the Program.

Currently, Site Operators are demonstrating EV technology through "ride and drive" programs in the Rose Bowl Parade and other high profile public events. They also organize charging station demonstrations, sponsor EV exhibits at community events and donate vehicles to other organizations. A few examples:

- Arizona Public Service sponsors the annual APS Solar & Electric 500 race.

- Texas A&M University has educated thousands of people through annual EV symposiums and demonstrations throughout their state.
- PEPCO, serving our Nation's capital, has conducted more than 25 major EV demonstrations since April 1992.

An effective partnership includes cost-sharing

The Site Operator Program allows DOE to leverage its limited resources – for every dollar of funding provided by the Program, the Site Operators contribute \$2.50. In addition, many Site Operators make large "in kind" contributions to the Program that are not directly included in these figures. For example, although only \$1.5 million was counted as their cost share, Southern California Edison's total EV R&D budget last year was actually more than \$10 million.

Plugged in to other industry efforts

Many Site Operators have built a network of state and local government contacts and have formed partnerships with organizations outside the DOE Program.

The Site Operator Program is also part of several consortiums that represent the majority of the major EV research efforts in the United States. These include Calstart, Tex-Start, Carolinas Consortium for Electric Vehicle Systems, Mid-Atlantic Electric Transportation Coalition, South Central EV Consortium, The Florida EV Consortium, Kansas Consortium and a number of others. The Site Operators are also involved with EPRI, EVAA, ETC, USABC and other key organizations on a diverse array of projects relating to testing, demonstrations and infrastructure development.

For further information, please contact:



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Heavy-Duty Engine Development Program— working toward a cleaner and more efficient diesel engine

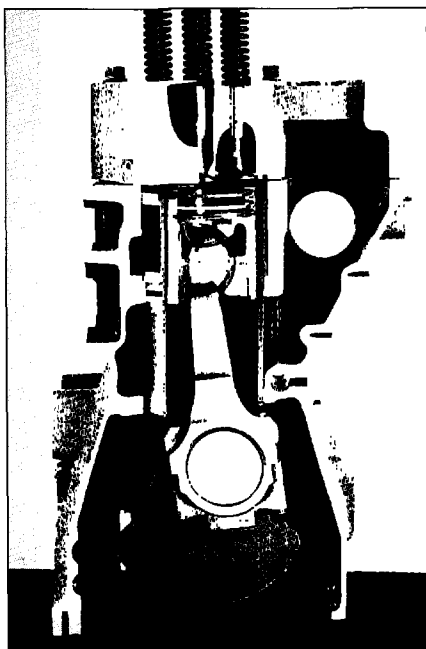
For decades, nearly every product that Americans eat or wear has been transported from producer to market by a vehicle equipped with a diesel engine. Diesel engines differ from gasoline engines in that they initiate fuel combustion by use of high pressure rather than by spark. This contributes to the diesel's unmatched efficiency and reliability, traits which, along with a well-established infrastructure, have made the diesel engine the cost-effective backbone of American commerce.

There is one drawback unique to the technology—diesel engines emit tiny, respirable particulates into the air. In addition, like gasoline engines, they emit NO_x, a pollutant which can cause urban smog, as well as CO₂, a greenhouse gas.

To improve efficiency and reduce emissions, the diesel engine industry has been continually improving upon the original diesel design, significantly reducing particulate, NO_x and CO₂ emissions. However, increasingly stringent environmental legislation is demanding emissions rates that are significantly lower than current diesel designs can achieve.

What can successfully replace the omnipresent, low cost and durable diesel engine? A team including the U.S. Department of Energy (DOE), the American diesel engine manufacturers and other cost-sharing partners says they have the answer—a new, advanced diesel engine. Their success under the auspices of the Heavy-Duty

Engine Development Program will significantly improve the diesel's environmental performance. In addition, their efforts to further improve diesel efficiency will substantially reduce America's dependence on foreign oil. And, a breakthrough diesel engine design will give the United States a valuable export, creating new domestic job opportunities. Indeed, such a design would be in great demand around the world, and countries including Japan and the U.K. also have aggressive diesel engine programs underway, heavily funded by their governments.



The innovative design of Cummins' Low Emission-55% (LE-55) Diesel Engine includes a spherically-seated piston, several ceramic components and the use of a synthetic liquid for cooling and lubrication.

A Program with several goals—in the short term

The two major goals of the Program focus on increased efficiency and reduced emissions. However, optimizing the engine for fuel efficiency is not always consistent with emissions goals, so a mix of technologies must be developed in tandem to allow the achievement of both goals.

The Program goal for energy efficiency is 55%, representing a 30% improvement over current production engines. This, in turn, would reduce CO₂ emissions by

20% or more. Low-emissions, 55% efficient (LE-55) engines are in development by the three largest American diesel engine manufacturers—Cummins, Caterpillar and Detroit Diesel Corporation. No specific concepts toward efficiency improvements are defined, but they are likely to include thermal optimization, increased utilization of exhaust and

Heavy-Duty Engine Development Program

the use of advanced materials to reduce friction and enable higher temperature operation.

Through joint efforts with industry and academic partners, the Program also seeks to develop technologies leading to greatly reduced levels of particulate and NO_x emissions. Based on standards set by the state of California, the goals are to bring particulate emissions down to .05 g/bhp-hr and NO_x emissions down to 2.0 g/bhp-hr—a reduction of 50% or more over current mandates. Here too, a wide range of technologies is being identified, evaluated and developed. These include fuel additives, synthetic lube oil, advanced particulate traps, electronic NO_x reduction with nonthermal plasma, advanced fuel injection equipment, and possibly catalytic converter technology. One especially impressive and promising technology developed under the Program is a fuel additive that can significantly reduce NO_x emissions in both new and existing engines. Principals in the effort include Dr. Rodney Sung and his staff at Texaco.

The Program is also chartered to support development in enhancing alternative fuels capabilities for diesel engines. Additional work in this area is conducted under a different DOE effort, the Alternative Fuel Truck Application Program.

In all cases, the Program emphasizes that every new engine design must demonstrate the

levels of cost-effectiveness, durability, maintainability and reliability that have made the diesel engine so valuable to American commerce. In addition, it gives priority to those technological advances that are likely to be commercially viable by the end of the decade.

An emerging mix of technologies can accomplish this and more

DOE and its private sector partners are confident that the goals of the program—regardless of the short timeframe—can not only be met, but exceeded. Prototype designs are within a few percentage points of efficiency goals, and testing under laboratory conditions already suggests diesel technologies which could bring particulate emissions below .01 g/bhp-hr and NO_x emissions to below 0.5 g/bhp-hr. If this success continues, the Program will allow America to continue to benefit from the power of the diesel engine—while breathing easier too.

For further information, please contact:



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Heavy-Duty Vehicle Emissions Testing Program— Giving fleet operators access to a convenient mobile testing lab

Heavy-duty vehicles such as trucks and buses play a valuable role in our economy, transporting both people and goods reliably and cost-effectively.

Most heavy-duty vehicles burn standard diesel fuel, which emits respirable particulates, as well as ozone-producing and greenhouse gases. As a result of increasing environmental and health concerns, the Federal and some local governments have initiated stricter emissions standards for heavy-duty vehicles.

To meet these standards, which will become more stringent over time, public and private sector heavy-duty fleet operators are investigating a number of potential solutions. These could include the use of alternative fuels, low sulfur diesel fuel, various fuel additives or a new generation of higher efficiency diesel engines.

Once test vehicles are put into service, fleet operators need a way to measure their emissions performance and compare them to their conventional vehicles. There are currently a handful of testing stations around the country. These stationary sites use technology that necessitates removing the

engine from the chassis, and they utilize a lengthy test protocol. In order to perform complete emissions tests on the heavy-duty vehicles, municipalities and companies must have their vehicles out of service for 3-4 days, not including the time it takes to travel to the site.

Bring the testing lab to the vehicle—and save downtime

Responding to this situation, DOE worked with engineers at the Department of Mechanical and Aerospace Engineering at West Virginia University to design and build the world's first transportable engine emissions testing laboratory for monitoring engine and emissions performance. It's a fully mobile facility on two trailer trucks, which can easily pull into any operator's site or convenient central area. Once in position, the bed of one of the trailers is lowered to the ground, and the vehicle to be tested is literally driven over the equipment on the bed and properly positioned. There's little set up and little vehicle preparation time, and a full battery of tests can be performed in less than a day, after which the vehicle can immediately return to normal



Heavy-Duty Vehicle Emissions Testing Program—

service. What's more, for qualified operators, the only "cost" involved with the service of the testing lab and its staff is an agreement to share the data generated.

Simulates driving conditions, screens for all major pollutants

Although the vehicle actually "drives" only on rollers, the testing system is able to simulate most real-world driving conditions that could impact emissions performance. Vehicle load of up to 40,000 pounds can be simulated, as can the effects of wind drag. In addition, the impact of gear shifting is taken into account by giving the driver/operator visual prompts via a computer monitor.

The mobile laboratory can measure particulate emissions, as well as gaseous emissions including carbon monoxide (CO), carbon dioxide (CO₂), nitrogen oxides (NO_x), methane (CH₄), methanol (CH₃OH) and formaldehyde (HCHO), as applicable to the particular vehicle type.

Testing a wide variety of vehicles all across the country

Since it was put into service in 1992, the mobile laboratory has tested hundreds of vehicles in dozens of fleets run by both municipal transit

authorities and private companies. Vehicles tested include large trucks, trailers, tractors, urban transit buses, school buses, refuse haulers and snow plows, running on fuels including natural gas, methanol, ethanol, liquefied petroleum gas (LPG), #2 diesel and low sulfur diesel.

Information disseminated to those who need it

In many cases, the data generated through these emissions tests represents new information regarding emerging alternative-fuel vehicle technologies. To ensure that this information is disseminated efficiently and for maximum benefit of fleet operators, it is stored centrally at the Alternative Fuel Data Center (AFDC), where it can be downloaded by qualified parties. Anecdotal information is provided to the National Alternative Fuels Hotline, a voice line established to provide objective information on alternative fuels and vehicles.

For further information, please contact:



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Ceramic Technology Program – developing cost-effective, high performance ceramic materials for use in a new generation of cleaner vehicles

The unique properties of advanced ceramic materials are vital in the development of a new generation of high performance, environmentally friendly vehicle heat engine propulsion systems. Because of their high temperature capabilities, ceramic materials used in gas turbines or hybrid vehicles can improve fuel economy by 30% or more, diminishing adverse environmental impact while reducing American dependence on foreign oil by a projected 275 million barrels annually. In addition, the wear resistance and low mass (density) of ceramics can also provide increased efficiencies in conventional and advanced piston engines.

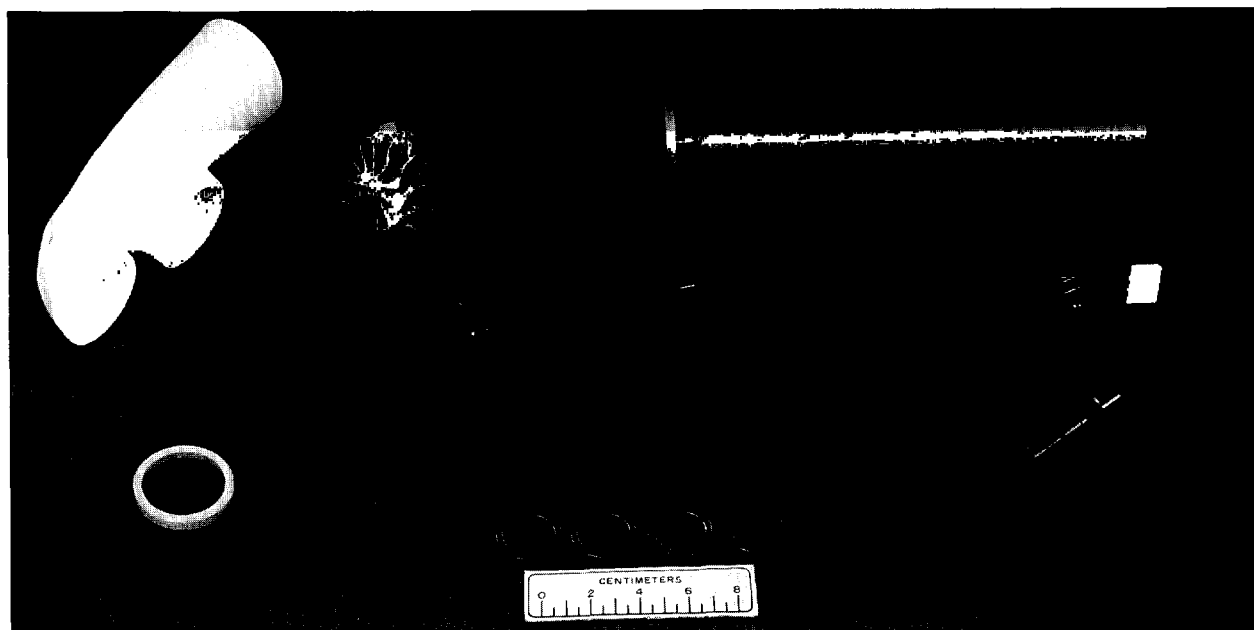
Building on success

In a previous effort—the 10-year long Ceramic Technology for Advanced Heat Engines Program—the Department of Energy successfully

improved synthesis and processing technologies to produce reliable ceramic materials for use in heat engines. The next step is to develop the manufacturing technology that will enable ceramics to become cost-effective for use in civilian ground transportation applications. This will enable American industry to bridge the gap between producing components in costly prototype quantities, and the automated production of large quantities of ceramic components for automotive applications.

Working with the private sector to develop an industrial base

Through the Program's Ceramic Manufacturing Initiative, a consortium of U.S. engine manufacturers and ceramic suppliers will produce simulated ceramic heat engine components in large quantities, gaining valuable experience in mass



A wide variety of ceramic components used in automobile and truck engines. However, their cost is still too high for most production applications in automotive engines.

Ceramic Technology Program

production. The lines will develop and employ advanced manufacturing techniques, including statistical process control, intelligent processing, and automation. Selected advanced ceramic processing and finish machining technologies will be scaled up as capabilities increase. The DOE will support these process integration activities with the objective of developing a U.S. industrial ceramics production base.

Linked with and supported by valuable government and industry resources

Since its inception, the Ceramic Technology Program's R&D planning has been developed in concert with industry. The private sector also shares program costs: 60% of appropriated funds are disbursed through competitive procurements to U.S. companies such as Norton, Allied Signal, Carborundum, General Motors and Caterpillar, who in turn share from 20% to 50% of project expenses. Project management and supporting research and technology are accomplished by the Oak Ridge National Laboratory.

The program also benefits from linkages with other government programs through formal agreements. These include:

- Support of international standards and ceramic machining activities at the National Institute of Standards and Technology and non-destructive evaluation activities at the Argonne National Laboratory
- A complementary DOE ceramic components development program managed by NASA
- A joint Transportation Technologies/DOE Defense Programs Ceramic Machining Program centered at the High Temperature Materials Laboratory in Oak Ridge, Tennessee.

This program builds upon these linkages by implementing cooperative research and development agreements (CRADAs) between automotive and ceramic industry representatives and government laboratories, as well as through collaborative R&D contracts.

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Fuel Cell Systems Research and Development Program – working toward a quiet, zero-emissions vehicle technology

Fuel cells produce electricity by combining hydrogen and oxygen atoms. Since they have no moving parts, they produce little or no noise. And, except for ordinary water, they produce near zero emissions in most cases. Nevertheless, fuel cell vehicles can offer the same performance as conventional gasoline and diesel-fueled vehicles.

The National Critical Technologies Panel selected fuel cells as one of 22 essential technologies that the U.S. must develop and utilize in order to achieve economic prosperity and energy security. Progress through cost-sharing efforts by government, industry and academic partnerships will accelerate the U.S. Department of Energy (DOE) R&D efforts to help make fuel cell-powered vehicles cost effective in the long term.

Fuel cells are a proven technology, used successfully in the American space program for more than three decades. The technological challenges remain in decreasing the cost and bulkiness of the fuel cell power system. The costs needed to meet these challenges would be far outweighed by potential economic, environmental and energy security benefits of success.

DOE's programs are designed to ensure that the U.S. maintains its position as a world leader in this important

area, and takes full advantage of the significant environmental and economic benefits of these systems.

Fuel cell buses can improve the quality of urban air

One of the fuel cell efforts underway is the development of an urban transit bus with twice the fuel efficiency and 99% lower emissions than standard diesel-powered buses. It will also be 10-20 decibels quieter, helping to further improve the quality of life in congested cities.

The Fuel Cell Bus project is a multi-phase effort to develop and demonstrate a bus powered by a methanol-fueled, phosphoric acid fuel cell (PAFC) propulsion system. In Phase I, contractors demonstrated feasibility by building and testing a half-size (25 kW) PAFC and battery system. Phase II



A bus powered by a phosphoric acid fuel cell/battery propulsion system

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A bus powered by a phosphoric acid fuel cell/battery propulsion system

The Partnership for a New Generation of Vehicles— Industry/government partners working to build an 80 mpg car and revitalize the American auto industry

In the 1950s, nearly all of the cars sold in America were made in America, as were more than 3/4 of the cars sold worldwide. With increasing competition from foreign automakers, the American auto industry, which accounts for 1 in 7 American jobs, has since lost substantial market share both domestically and abroad. The domestic market share for American cars slipped below 75% in the late 1980s, and, by the early 1990s, fewer than 20% of the cars on roads worldwide were made in America.

Individual automobile manufacturers have in recent years made significant inroads in reversing these trends, further improving the quality and value of their products. In 1993, they recognized an opportunity to achieve a quantum leap in strengthening U.S. automotive competitiveness by leveraging the expertise of a diverse group of private and public sector partners.

Effort begun by Presidential initiative

The Partnership for a New Generation of Vehicles (PNGV) is a result of a vision shared by President Clinton, Vice President Gore, and the CEOs of the Big Three automakers—Chrysler, Ford, and General Motors. They joined together on September 29, 1993 to announce that they would work in tandem to achieve three aggressive, interrelated R&D goals:

- develop manufacturing techniques to reduce the time and cost of automotive development

- improve fuel efficiency and emission performance
- develop a vehicle with up to three times the fuel efficiency of today's cars while maintaining or improving safety, performance, and price

The first two goals are shorter term and will help form a foundation for meeting the third and most ambitious goal. An aggressive timetable has

been established, with a concept vehicle capable of providing 80 miles-per-gallon due within six years and a production prototype due within ten years.

An unprecedented scope of industry/government cooperation

In early 1991, Chrysler, Ford, and General Motors formed a historic cooperative partnership called the U.S. Council for Automotive Research (USCAR) to share technology in selected research areas. In one effort under the USCAR umbrella, the U.S. Advanced Battery Consortium, the Department of Energy joined with USCAR to pool technical resources and expertise to

develop electric vehicle batteries with greater storage capacity quickly, effectively, and cost-effectively.

These efforts laid the groundwork, but the scope of the partnership represented by PNGV is on a scale never before envisioned. Led by the Department of Commerce (DOC), it includes nearly every area of the Federal government involved with transportation-related technologies and policies: DOC, Department of Defense (DOD), Department of Energy (DOE), Department of Transportation (DOT), National Aeronautics and Space Administration (NASA), Environmental Protection Agency (EPA),



President Clinton announces a partnership with automakers for developing the car of the future.

The Partnership for a new generation of vehicles

National Science Foundation (NSF), as well as the Office of the Vice President, Office of Science and Technology Policy, Office of Management and Budget, Office of Environmental Policy and National Economic Council. Of all the Federal agencies, DOE has been most involved in automotive technologies and has dedicated the most significant budget to accelerating the PNGV goals.

The resources of all these organizations are being joined with the extensive resources of the Big Three automakers to meet ambitious goals. In the future, American academia, related manufacturers, industry suppliers, and others will likely join the partnership effort.

The PNGV Operational Steering Group, consisting of representatives from both private and public sector partners, identifies and prioritizes research projects. The PNGV Technical Task Force will then build task-oriented project teams whose members will be chosen from among all partners for maximum effectiveness. The creation of a master Cooperative R&D Agreement (CRADA) has helped streamline the process of private and public sector partnering, and will likely serve as a model for future efforts.

Combining pockets of isolated expertise

The scope of the R&D work needed to meet the PNGV goals would likely be cost-prohibitive for a single or even a small number of organizations. In addition to cost-sharing, the extensiveness of the partnership offers many precedent-setting opportunities to combine and build upon complementary technologies that may have been developed separately for other purposes. As examples, DOD has extensive expertise in advanced materials areas developed originally for high tech weapons programs; NASA has state-of-the-art systems integration expertise developed through work on the space shuttle; and DOE offers technologies developed in materials, alternative fuels and propulsion systems areas through decades of cutting-edge R&D work. These and other pockets of expertise may be combined as PNGV moves forward.

A wide variety of technologies in the portfolio

It is too early to determine which specific technologies will lead the way in meeting the three goals or what form the New Generation Vehicle may take, but there are a number of technologies which will be considered in both the shorter- and longer-term. These include: advanced manufacturing technologies, lightweight materials, high-performance computing, alternative fuels, fuel cells, fuel reformers, hybrid vehicles, batteries, ultracapacitors and flywheels, efficient air conditioning systems, and low emissions technologies.

The end result will be a vehicle similar in size, range, acceleration, and interior volume to today's Ford Taurus, Chevy Lumina, or Chrysler Concorde. It will also have equivalent in-use safety performance and a comparable sticker price, adjusted for future economics.

A wide range of benefits for the U.S.

The New Generation Vehicle will significantly benefit the American auto industry, the American economy, and the environment. A more competitive auto industry will improve our balance of trade, keeping more dollars in the domestic economy. And, if the Vehicle utilizes a domestic fuel, as it is likely to do, the domestic economic benefits are further compounded. The effort will also strengthen one of the largest employment sectors of the American economy, creating and sustaining quality jobs. In addition, the widespread use of vehicles of substantially higher fuel efficiency will mean substantially lower emissions per mile driven and help to improve the quality of our air.

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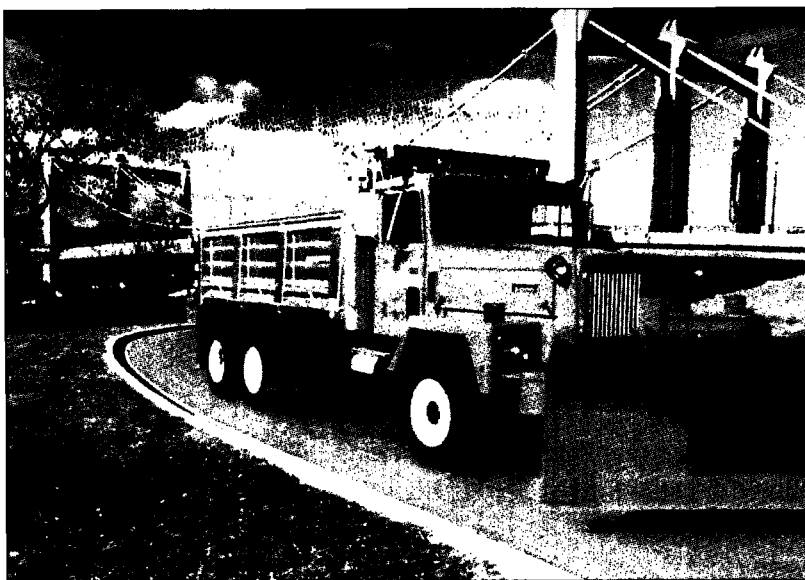
Alternative Fuel Truck Application Program— enabling the use of cleaner, domestically-sourced fuels in the heavy-duty transport sector

Hheavy-duty trucks are the backbone of the American economy, moving nearly all food and manufactured products to the marketplace cost-effectively, efficiently and reliably. But like vehicles in many other sectors of the economy, heavy-duty vehicles must soon begin meeting stricter federal emissions regulations in order to stay in operation.

Thousands of operators in a crucial segment of the American economy will be faced with a decision on how to best meet these requirements. Their options may include cleaner, advanced diesel fuels currently being developed by the petroleum industry; new diesel engine technologies being developed through efforts such as the Heavy-Duty Engine Development Program under the U.S. Department of Energy (DOE); or use of one of several alternative fuels.

Although the use of alternative fuels such as alcohols, natural gas and propane is not federally mandated for heavy-duty vehicles—as they are for cars and light-duty vehicles—alternative fuels may offer operators a cost-effective means for meeting the requirements. In addition, many operators may be faced with local or state laws which do mandate use of alternative fuels—another factor they'll need to consider. And, they may find that use of domestically-sourced alternative fuels may be the best option for aligning themselves with America's energy security goals.

To help give operators some of the information they need to make an informed decision, DOE is working with numerous industrial and municipal partners to study the use of different alternative



Ethanol-powered snowplow operating in Hennepin County, MN

fuels in heavy-duty vehicles. This body of information is also provided to engine manufacturers to assist them in their R&D efforts and in optimizing new technologies.

Helping generate and disseminate needed information

The Alternative Fuel Truck Application Program is designed to collect data from as many different user sectors using as many different types of vehicles and fuels in as many geographical areas as possible. Program-supported fleets, for example, encompass delivery trucks to tractor trailers, running on a diversity of fuels including methanol, ethanol, natural gas, propane and clean diesel. Fleets are located from California to New York and from Florida to Minnesota, and include operators as diverse as Federal Express, Roadway Trucking, Tampa Electric and Coors Brewing Company.

Alternative Fuel Truck Application Program

The Program gathers information from fleets under a number of different funding arrangements. Some are fully cost-shared by DOE. Others are fleets encouraged to begin their own "prove-out" programs by DOE paying the cost differential between conventional vehicles and alternative-fuel vehicles. Still others are not DOE-funded, but are structured to share information back and forth under different types of agreements.

User-liaison organizations are another important component of the effort. For example, the American Trucking Association, which represents hundreds of fleet owners, shares DOE-collected information with its members, and also makes data available from other programs for wider dissemination.

The Program also includes a component aimed at gathering data on school buses, refuse haulers, street sweepers and other heavy-duty municipal vehicles. This effort likewise includes fleets from all across the country operating under different funding agreements. Participants include Tulsa County, Oklahoma; Wood County, West Virginia; the Town of Weston, Massachusetts; and Maricopa County, Arizona.

Information collected from Program efforts flows to the Alternative Fuels Data Center, where it can be accessed by the private sector. Information is also disseminated through the National Alternative Fuels Hotline (1-800-423-1DOE).

Helping advance the state-of-the-art

One of the objectives of the Program is to encourage manufacture of original equipment heavy-duty alternative-fuel vehicles, as opposed to converted vehicles. For this reason, the Program has developed close ties with major engine manufacturers to provide them with in-use information on their alter-

native-fuel products—many of them in the prototype or pre-commercial stage.

Engines developed by major U.S. heavy-duty engine manufacturers including Detroit Diesel Corporation (DDC), Caterpillar, Cummins, Hercules and Tecogen are included in DOE-supported fleets. Current R&D efforts include DDC's natural gas-powered diesel engine and Caterpillar's multi-fuel alcohol diesel engine.

Paving the way for greater alternative fuels use—and greater energy security

Congress has directed DOE to help drive alternative fuels so that they "reach a threshold level of commercial application and consumer acceptability at which they can successfully compete with petroleum-based fuels." Aimed at making these goals a reality in the trucking and related sectors, this Program will help provide potential users with the real-world cost, emissions and performance data they need to confidently invest in new technologies, as well as help improve available technologies, thereby helping to create a viable alternative-fuel vehicle industry and infrastructure.

In so doing and in the larger sense, the Program will help meet the key goals of America's energy-related legislation—to improve national security by using more domestically-produced fuels and less imported petroleum, while improving environmental performance and creating new job-producing industries.

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The U.S. Advanced Battery Consortium—automakers and DOE team up to establish American leadership in new automotive technology

The environmental benefits of zero-emitting electric vehicles (EVs) are substantial, but the lack of a battery capable of providing the range and performance that would be acceptable to the consumer has proven to be a major drawback in their development. American, Japanese and European companies and consortia are actively working on producing advanced batteries that can help make EVs practical for everyday use. If American industry can take the lead now, it could herald an era of American dominance in a new automotive arena, as well as significantly further our nation's energy security goals.

The Big Three team up with DOE and others to lead the way

The level of R&D effort required to adequately explore all the promising battery technologies would be expensive and time consuming. It would not be practical for any one company to perform this level of activity while still meeting its responsibilities to its employees, customers and other stakeholders. On January 31, 1991, Chrysler, Ford and General Motors, the Big Three American automakers, entered an agreement to pool their technical knowledge and funding, looking to accelerate progress by collectively combining expertise and reducing individual risk. Their partnership is called the United States Advanced Battery Consortium, or USABC.

The U.S. Department of Energy (DOE), which has long had extensive battery-related R&D activities underway, joined the partnership later in the year, providing expertise and funding. DOE also acts in an advisory and oversight role for various USABC committees and projects.

To make EVs practical in the shortest possible timeframe, many battery-related issues—such as

standardization of charging systems—must be settled early on. As part of the partnership, the Electric Power Research Institute (EPRI), the technical research arm of the electric utility industry, and several individual utilities are providing vital input, as well as funding and staff.

The partnership among the Big Three is slated to run 12 years. The cooperative agreement between the Big Three and DOE covers a period of four years and establishes funding of \$260 million, cost-shared equally between government and industry.

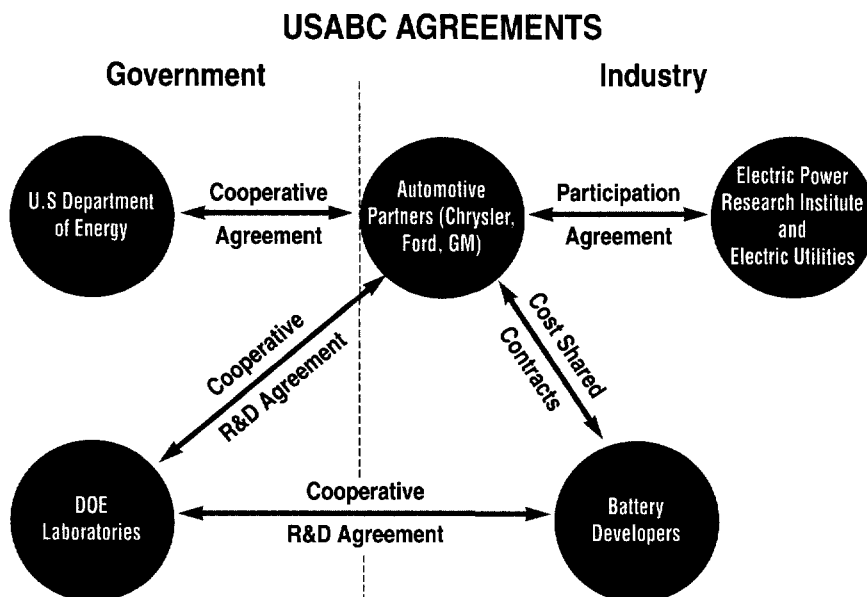
The focus is on batteries

The key to making EVs practical is the development of batteries that can provide performance comparable with conventional vehicles, and at comparable cost. Today's lead acid batteries have limited range, allowing drivers to travel only relatively short distances before they must recharge. Sustainable speeds, also, are not in line with those demanded by today's consumers. Current technology provides batteries with an energy-to-weight ratio of 30-40 watt hours per kilogram, at a cost up to \$150 per kilowatt hour.

USABC has set a mid-term goal to have in prototype production by 1995 batteries with energy-to-weight ratios of 80-100 watt hours per kilogram, at a cost of less than \$150 per kilowatt hour. Other goals include power-to-weight ratios of 150-200 watts per kilogram and a five-year useful life. Nickel-metal hydride, as well as sodium-sulfur and other sodium-beta batteries, are the likely technologies to meet these goals.

The Consortium has also set longer-term goals, looking by late in the decade to have batteries in prototype production that can provide an energy-to-weight ratio of 200 watt hours per kilo-

The U.S. Advanced Battery Consortium



gram at a cost of less than \$100 per kilowatt hour, as well as power-to-weight ratio of 400 watts per kilogram and a 10-year useful life. Lithium-iron disulfide and lithium-polymer batteries are the most promising technologies to meet these goals, and other technologies are also being investigated.

USABC's mid-term goals are consistent with the need to introduce EVs that meet California automotive emissions regulations by 1998. The longer-term goals are designed to produce zero-emitting EVs that are competitive in every way with conventional gasoline automobiles.

Diverse projects underway

Working toward both mid- and longer-term goals, USABC has awarded a number of research contracts to outside groups for work on specific battery technologies. These include Ovonic Battery Corporation (nickel-metal hydride), Silent Power (sodium-sulfur), Saft America (nickel-metal hydride, lithium-iron disulfide), and two multi-company efforts led by W.R. Grace and 3M (lithium-polymer). Where foreign-owned companies are involved, at least 50% of the batteries produced for the U.S. auto industry must be

manufactured in the United States.

USABC is also sponsoring technical projects at several DOE National Laboratories, by way of Cooperative Research and Development Agreements (CRADAs) which make it easier to partner government and private sector resources. DOE laboratories involved include Lawrence Berkeley National Laboratory, National Renewable Energy Laboratory, Argonne National Laboratory, Sandia National Laboratory and Idaho National Engineering Laboratory.

A model for intercompany and government/industry partnerships

USABC is actually only one of many partnerships among otherwise competitive American automakers. Chrysler, Ford and General Motors have joined forces under the U.S. Council for Automotive Research (USCAR) to tackle many crucial automotive technology challenges and help boost the competitiveness of American industry. USABC is one of the largest ventures under the USCAR agreement.

In addition, the automakers and DOE have, through USABC, developed and pioneered several new procedures that could maximize the success of government/industry partnerships, and could lead the way toward more such partnerships in the future.

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The Federal Fleet Program—paving the way for widespread use of alternative-fuel vehicles

The potential benefits of widespread use of alternative-fuel vehicles (AFVs) can be substantial: increased energy security because of a reduction in the need for foreign oil, creation of new American jobs in industries stimulated by the demand for domestically-sourced fuels, and cleaner air resulting from potentially lower-emitting fuels and technologies. However, widespread use of compressed natural gas, propane, ethanol, methanol, electric, hybrid electric and other AFVs has been constrained by a "chicken or the egg" dilemma: without a convenient fueling and maintenance infrastructure, drivers and fleet operators are reluctant to consider AFVs; and, without a volume of AFVs on the road, business people are reluctant to invest in building infrastructure.

Through the Federal Fleet Program, the federal government is taking the lead to solve this dilemma, striving to concentrate a volume of same-type AFVs in a given area. This creates a ready local market for needed services and enhances the practicality of AFV operation for both public and private sector fleets. And, in turn, encourages expanded AFV manufacture and development.

Program becoming increasingly aggressive

The roots of the Federal Fleet Program are in the Alternative Motor Fuel Act and in Executive Order 12759, signed by President Bush in April 1991. The Order set the first AFV acquisition targets for federal agencies, and these targets were reiterated in the Energy Policy Act of 1992.

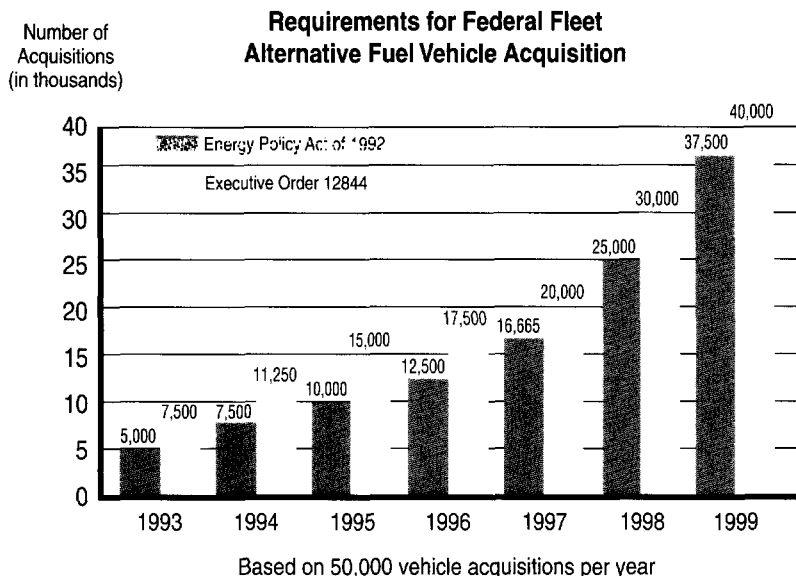
In early 1993, through Executive Order 12844, President Clinton built upon these goals, accelerating acquisition targets by as much as 50%. Requirements for federal AFV acquisition now stand at 7,500 for 1993; 11,250 for 1994; 15,000 for 1995; 17,500 for 1996; 20,000 for 1997; 30,000 for 1998; and 40,000 for 1999 and thereafter.

Through the Program, AFVs will be purchased to expand fleets or replace vehicles that would be going out of service, and targets are based on average annual federal fleet purchases of 50,000 vehicles.

To assist agency offices in acquiring these vehicles, which will be used in the course of their regular day-to-day business, the Program has committed to funding the increment between the cost of the AFV and the cost of a comparable conventional vehicle. The base price, as before, is the responsibility of the individual agency.

Partnership with local municipalities creates win-win situation

As part of his acceleration of the Federal Fleet Program, President Clinton established a Federal Fleet Conversion Task Force to recommend the best



Federal Fleet Program

ways to meet the acquisition and vehicle placement goals. One of the Task Force's key recommendations was the establishment of the Clean Cities Program, which allows local communities to recommend the types of AFVs to be acquired by federal government offices in their area. The individual community will then acquire a certain number of the same type of vehicles for its own use. In this way, concentration levels—and the local market for needed AFV services—can increase at a faster pace. This in turn makes it more beneficial for local private sector fleets to begin or expand their purchases of AFVs.

In addition, the effort could potentially help the city clean up its own air, and more cost-effectively meet any mandatory requirements it may face under the Clean Air Act Amendments or other legislation.

Interagency cooperation and industry outreach

In addition to working with field agency locations and state governments, the Program also creates close working partnerships between the U.S.

Department of Energy (DOE) and the General Services Administration, the federal agency responsible for purchasing. There is also close coordination with the U.S. Postal Service and the Department of Defense, two federal bodies especially active in AFV issues. Within DOE, the Program is linked with the Light-Duty Vehicle Emissions Testing Program, to which it provides its vehicles for testing. In addition, the Program is stimulating communication with AFV manufacturers and other private sector suppliers with the capabilities to further AFV practicality and availability. Through the Federal Fleet Program, all levels of government and private industry are working together to help our nation achieve its energy security, employment and environmental goals.

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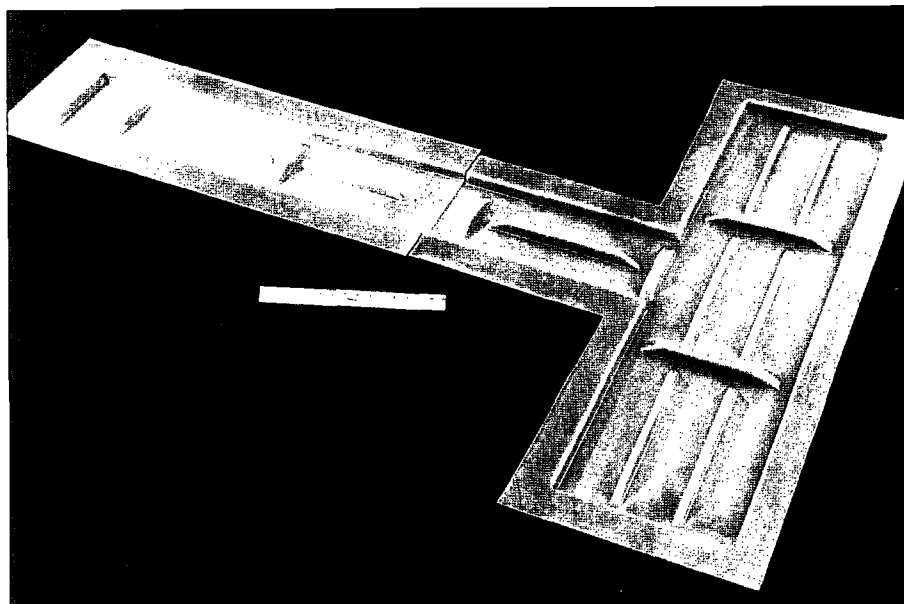
Materials for Lightweight Vehicles Program – helping develop lighter, more fuel efficient, safer cars

Extensive use of a wide range of lightweight/high strength materials in the manufacture of gasoline-powered automobiles could lead to cars that provide 50-70% better fuel efficiency yet are comparable in size, comfort and safety to today's family vehicles. These reduced-weight vehicles could reduce our demand for imported oil by more than one million barrels *per day* by the year 2010.

In addition to substantially improving the fuel economy of "conventional" vehicles, these materials are critical to the successful market competitiveness of zero-emission electric vehicles (EVs), as they will enable designers to achieve the range and responsiveness required to make EVs acceptable to the American consumer.

Currently, materials such as polymer and metal matrix composites, ordered intermetallics and aluminum alloys are used primarily in aerospace applications, and are not yet cost-effective for use in the competitive automotive market. Much of the high cost of these materials technologies can be attributed to materials costs, process and manufacturing procedures, and costs associated with the inability to design with new materials, especially with regard to composite materials.

The objective of this new Program, initiated in 1993, is to work in cooperation with U.S. automakers and their materials suppliers to develop the materials technology that will allow greater use of lightweighting materials in the manufacture of lighter, fuel efficient and safe fam-



Complex single sheet aluminum component formed by advanced manufacturing process

ily vehicles. Efforts focus on synthesis, processing and advanced materials forming and manufacturing techniques, development of which can help make lightweight materials cost competitive with conventional sheet steel.

Development of these technologies can lead to more energy efficient vehicles, decreasing reliance on foreign petroleum and reducing adverse environmental impacts. It can also improve the international competitiveness of the U.S. auto industry, helping to preserve jobs for American workers.

Building on DOE materials knowledge

Many high-tech lightweight materials, such as carbon fiber-reinforced polymer matrix composites, already exist, but the knowledge to *cost-competitively* design and manufacture automotive systems and components from these materials does not. Now, the technology must be developed that will

Materials for Lightweight Vehicles Program

lower costs to levels that allow industry to competitively manufacture automobiles from these materials.

Focus on new and better ways to work

The Program will support process integration R&D activities, including the development of:

- Lower cost processing and manufacturing techniques
- Alternative synthesis and processing routes
- Methods to interface advanced materials with conventional materials
- Easier-to-manufacture composite matrices
- New software design tools
- New computational analysis techniques for materials synthesis and safety testing
- Technologies for effectively recycling lightweight materials

Strong linkages with industry and other areas of government

This Program supports collaborative R&D efforts with the auto industry and its suppliers; the DOE Office of Transportation Materials has already established strong linkages with these industrial groups. The need for R&D to lower the cost of advanced lightweight materials for ground transportation has been established through interactions with representatives of the industry through their trade association, the American Automobile

Manufacturers Association (AAMA), and the concept of a government/industry cost-shared program has received strong industry support. A five-year R&D Program Plan has been developed as a result of these industrial interactions.

Linkages have also been established with the Automotive Composites Consortium (ACC) and the U.S. Automotive Materials Partnership (USAMP) which operates as one of 13 consortia under the umbrella organization, U.S. Council for Automotive Research (USCAR). In addition, aerospace companies such as Boeing and GE, which make extensive use of these materials for aerospace applications, are involved.

Other federal agencies are involved in the Program through the Committee on Materials (COMAT) out of the White House Office of Science and Technology Policy (OSTP). These include the National Institute of Standards and Technology (NIST), participating through a formal interagency agreement, U.S. Department of the Interior/Bureau of Mines, DOD/ARPA and NASA.

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